Air Pollution and Health Effects: A Study of Medical Visits among Children in Santiago, Chile

Bart D. Ostro,[1] Gunnar S. Eskeland,[2] Jose M. Sanchez,[3] and Tarhan Feyzioglu[4]

[1]California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Berkeley, CA 94704 USA; [2]The World Bank, Policy Research Group, Washington, DC 20433 USA; [3]Universidad de Chile, Santiago, Chile; [4]International Monetary Fund, European Department, Washington, DC 20433 USA

Many epidemiological studies conducted in the last several years have reported associations between exposure to airborne particulate matter, measured as PM_{10} (<10 µm in diameter), and daily morbidity and mortality. However, much of the evidence involves effects on the elderly population; there is less evidence about the effects of particulates on children, especially those under 2 years of age. To examine these issues, we conducted time–series analyses of 2 years of daily visits to primary health care clinics in Santiago, Chile, where counts were computed for either upper or lower respiratory symptoms and for cohorts of children 3–15 years of age and below age 2. Daily PM_{10} and ozone measurements and meteorological variables were available from instruments located in downtown Santiago. The multiple regression analysis indicates a statistically significant association between PM_{10} and medical visits for lower respiratory symptoms in children ages 3–15 and in children under age 2. PM_{10} is also associated with medical visits related to upper respiratory symptoms in the older cohort, while ozone is associated with visits related to both lower and upper respiratory symptoms in the older cohort. For children under age 2, a 50-µg/m³ change in PM_{10} (the approximate interquartile range) is associated with a 4–12% increase in lower respiratory symptoms. For children 3–15 years of age, the increase in lower respiratory symptoms ranges from 3 to 9% for a 50-µg/m³ change in PM_{10} and 5% per 50 ppb change in ozone. These magnitudes are similar to results from studies of children undertaken in Western industrial nations. *Key words*: air pollution, children, Chile, morbidity, particulate matter, PM_{10}, respiratory. *Environ Health Perspect* 107:69–73 (1999). [Online 14 December 1998]
http://ehpnet1.niehs.nih.gov/docs/1999/107p69-73ostro/abstract.html

The 4.5 million inhabitants of Santiago, Chile, are exposed to high levels of air pollution during a significant part of the year. Located in the western side of South America, the city frequently confronts strong anticyclonic conditions that cause a thermal inversion layer at a height of 600–900 m above sea level. The city is in the middle of a valley at an average altitude of 570 m above sea level and is surrounded by two mountain ranges: the Andes mountains and the Cordillera de la Costa. These geographic conditions restrict ventilation and dispersion of air pollutants within the valley. Such features explain why Santiago, with emission levels similar to those in other cities, experiences high atmospheric contamination levels.

Data from the Chilean Health Service show that the standard for the 24-hr average of particulate matter below 10 µm in diameter (PM_{10}), 150 µg/m³, is exceeded throughout the winter. The average annual concentrations of PM_{10} exceed Chile's standard of 50 µg/m³ by a factor greater than 2. The 1-hr standard for carbon monoxide is exceeded in 20% of the data collected during the winter time, while 1-hr ozone often exceeds 0.09 ppm during the summer (*1*). These levels of atmospheric pollution are likely to cause health effects among the population of Santiago. Recent research used time–series data to examine the association of PM_{10} and daily mortality between 1989 and 1991 in Santiago (*2*). The

results obtained suggest a strong association between these two variables even after controlling for several potential confounders including temperature, season, month, and day of the week. However, there have been few studies completed in Chile on the effects of PM_{10} pollution in relation to respiratory illness in Santiago. In addition, on a worldwide basis, there are only a few epidemiologic time–series studies of the effects of air pollution on the health of children and infants (*3–5*). Studies in the developing world are important because the extent to which findings from industrialized countries can be extrapolated to other areas is uncertain (*6*).

This paper examines how weather conditions and air pollution influence the likelihood of medical visits among children in Santiago. Data on morbidity due to respiratory diseases among children under 15 years of age have been collected from a group of public primary health clinics. In Chile, almost 75% of the population are members of the public health care system, which serves primarily the lower 70% of the population income distribution.

Methods

Morbidity, Air Pollution, and Weather Data

In Santiago there are about 70 primary health care centers (clinics) in the public

health care system. On average, they provide service for infants with 10–20 doctor hr/day/clinic. During 1992, there were close to 1,830,000 medical visits for pediatric morbidity in the metropolitan area excluding well-child and annual physical examinations (*7*).

The Infant Respiratory Disease Program was developed by the Chilean Ministry of Health to provide effective care at the clinics and to evaluate the epidemiology of pediatric illnesses. A monitoring program for infant respiratory disease provides information from 12 primary health provision centers, designated as sentinel clinics (*8*). The present research used information from eight sentinel clinics between 13 July 1992 and 31 December 1993. These clinics serve 12% of the child population in the province (n = 153,548) (*9*).

Santiago is divided into six Public Health Services Areas. The clinic selection process followed a criterion that allowed choosing at least one clinic in each health service area. Three of the 12 clinics were excluded because of missing values or insufficient information. An additional clinic was excluded because it was more than 12 km from the nearest air pollution monitoring station. With the eight remaining clinics, each of the city's six health service areas was represented. Using a standardized form, the total number of child medical visits and respiratory morbidity diagnoses was collected every day. Doctors working at each clinic prepared the diagnoses. The researchers of the infant respiratory disease program trained the record-keeping staff at each clinic to group the diagnoses observing the following classifications: 1) nonrespiratory visits,

2) respiratory visits due to upper respiratory symptoms (URS), and 3) respiratory visits due to lower respiratory symptoms (LRS). In this case, URS included inflammation processes that affected the respiratory tract above the larynx such as pharyngitis, common cold, adenoiditis, sinusitis, tonsillitis, and otitis media. LRS included inflammatory processes affecting the larynx, trachea, bronchus, or lungs such as bronchitis, pneumonia, bronchopneumonia, bronchial asthma, acute obstructive bronchitis, acute laryngitis, and acute tracheitis. When there were two or more simultaneous diagnoses, the most serious one was recorded. The original data collection separated the children in two age groups: less than 2 years old and children from 2 to 14 years old. For each day, the number of medical visits with each diagnosis was totaled across clinics. Each clinic serves an average of 2,600 children under age 2 and about 16,000 between ages 3 and 14.

The clinics are only open during working hours Monday through Friday; however, the number of doctors attending to patients at the clinics (in "pediatric hours") varies from day to day. This fact implies that the supply of medical attention varies accordingly. Some patients do not seek medical attention because of the limited hours of clinic operation and also because of clinic capacity restrictions (as evidenced by long waits). While the extent of unsatisfied demand cannot be known with certainty, each clinic made a daily record of the number of pediatric hours available for morbidity visits.

The recorded data reflect medical visits in general and do not discriminate between first visits or follow-up visits; consequently, the data capture the number of visits and not the number of episodes. Out of the 370 planned days of observations (excluding weekends and holidays), there was information for 352 days from the eight clinics; the remaining days were not included because there were fewer than eight clinics fully functioning. In addition, 9 days were excluded as outliers because they were holidays or because of labor disputes. Table 1 provides the general descriptive statistics of the data. There was an average of 565 visits/day among the eight clinics surveyed. Sixty-three percent of all medical visits of children under 15 years old were for respiratory illness. Among these, 60.3% were for LRS.

The health end points studied represent children who were successful in obtaining a doctor's attention and who were then diagnosed with respiratory illness. Assuming that diagnoses were without error (or with errors independent of the pollutant and temperature variables), some parents did not seek treatment for their children, some took them to hospital emergency rooms, and some who took them to clinics may have been unsuccessful in obtaining a doctor's attention due to lack of capacity. These actions may have resulted in an attenuation or flattening of the estimated dose–response function at the higher pollution concentrations.

Daily data for temperature, PM_{10}, and ozone were available from the Metropolitan Environmental Health Service. PM_{10} was monitored by a low-volume dichotomous sampler, and ozone was collected using the chemioluminescent principle. The average of the four stationary monitors located downtown within a 12-km^2 quadrilateral was used to obtain the daily concentrations of PM_{10} and ozone. The correlations of PM_{10} with ozone and temperature were -0.1 and -0.45, respectively, and the correlation for ozone and temperature was 0.67.

Analyses

Examination of the daily counts for reported medical visits for upper and lower respiratory symptoms for infants below 2 years of age (young) and between ages 3 and 15

(older) supports distributional assumptions allowing ordinary least squares as the principal statistical analysis (the counts show no truncation and appear normally distributed). Each age group was examined separately for both upper and lower respiratory visits for a total of four different models. To develop our regression model, we determined the best fit of several covariates prior to the entry of air pollution into the model. In turn, we examined the association of each outcome with daily average temperature and humidity (lagged up to 4 days), day of the week, season (or month), and year of the study. Day of the week was likely to be important because the clinics were closed on weekends. Visual inspection of the data indicated clear seasonal patterns. Once the covariates with the strongest association were determined, PM_{10} was entered into the model. Contemporaneous exposure and lags up to 4 days were examined. All models were corrected for autocorrelation using AUTOREG in SAS (10).

In the second analysis, seasonality was modeled as a locally weighted (Loess) smooth of time using a general additive model (GAM) in S-Plus (11,12). The Loess smoothing technique can accommodate nonlinear and nonmonotonic functions, offering a more flexible nonparametric modeling tool. In using the Loess smooth, each observed value is replaced by a predicted value, generated by connecting the central point from a weighted regression for a given span (neighborhood) of the data (13). The weights of the regression are reduced as one moves further from the central point. For our purposes, we chose a span that included 20% of the data, or approximately 3 months. The model was then checked to ensure that no serial correlation remained in the data. We also tested the sensitivity of the results to alternative spans of the data. Because smoothers are an effective means of controlling for seasonality, we used this model to explicitly examine alternative lags in air pollution.

A second and third sensitivity analysis involved rerunning the model after dropping

Table 1. Summary statistics of air pollution and temperature data for the eight clinics during the study period, 13 July 1992–31 December 1993

	Daily mean	Max–min values
Total visits	565.0	859–376
Total visits <2 years old	221.9	316–136
Respiratory illness		
Total visits	357.1	704–166
Total visits <2 years old	152.8	310–66
Lower respiratory illness		
Total visits	215.4	440–71
Total visits <2 years old	104.3	202–42
Upper respiratory illness		
Total visits	141.6	290–69
Total visits <2 years old	48.5	80–24
PM_{10} (24-hr average µg/m^3)	108.6	380–18.5 (135.5–70.3)
Ozone (1-hr maximum, ppb)	56.2	176–10 (77–31)
Temperature (24-hr average, °C)	15.8	23.7–5.4 (20.2–11.5)

Max–min, maximum to minimum. Interquartile (75th–25th) range is shown in parentheses.

Table 2. Ordinary least squares regression results for clinic visits for upper (URS) and lower respiratory symptoms (LRS) in young (<2 years old) and older (3–15 years old) children (estimated β-coefficient with standard error in parentheses)

	Young	Young, LRS	Young, URS	Older	Older, LRS	Older, URS
PM_{10}	0.076 (0.026)**	0.061 (0.020)**	0.004 (0.012)	0.124 (0.042)**	0.076 (0.028)**	0.052 (0.022)*
Ozone	0.053 (0.043)	0.031 (0.036)	0.021 (0.020)	0.222 (0.069)**	0.109 (0.046)*	0.117 (0.035)**
PM_{10} and ozone together						
PM_{10}	0.069 (0.028)*	0.056 (0.022)**	0.001 (0.013)	0.088 (0.045)*	0.062 (0.029)*	0.029 (0.024)
Ozone	0.013 (0.048)	0.002 (0.037)	0.015 (0.023)	0.227 (0.076)**	0.104 (0.049)*	0.120 (0.041)**

The model also includes daily average temperature (1-day lag); binary variables for day of week, month, and year; and corrections for autocorrelation. PM_{10} (µg/m^3) and ozone (ppb) are unlagged.
*$p<0.05$; **$p<0.01$.

the days with the highest 5% of PM_{10} concentrations (PM_{10} >235 μg/m³) and the coldest 5% of the days (<8°C). Fourth, we reran the GAM model without the monthly binary variables since these variables are correlated with PM_{10} levels and their inclusion may result in "overcorrection." Once seasonal patterns in respiratory symptoms were controlled for via the smooth of time, month per se should have had little additional influence on symptoms. Fifth, to additionally test the influence of season, the regression was rerun for only the 8-month nonsummer period by excluding November through February from the analysis of this southern-hemisphere city. Finally, we examined the models after inclusion of a second pollutant, ozone, was added to the specification.

Results

In general, the best fit for the ordinary least squares model included average temperature (lagged 1 day, although same-day temperature performed almost as well), day of the week, and dichotomous variables for each month and year. Medical visits associated with LRS were highest on Monday and Friday. For URS, there was little difference by day of week. Three of the four outcome measures (i.e., young lower, older lower, and older upper symptoms) peaked during the winter months. Visits for URS for those below 2 years of age had a less distinct seasonal pattern, with some peaks in March, April, and May. For the older subgroup, there was no evidence of serial correlation in the error terms, while for the younger subgroup, a three-period correction effectively reduced the serial correlation, based on the Durbin-Watson statistics. As summarized in Table 2, there was a statistically significant association between PM_{10} and LRS in both the young and older cohorts, between PM_{10} and URS in the older cohort, and between ozone and URS and LRS in the older cohort. Inclusion of a term for linear time trend did not alter the results. The models explained about 80% of the variation in visits for LRS, about 70% of the variation in visits for URS in older children, and about 20% of the variation in the URS visits of infants. Models containing both PM_{10} and ozone did not change significantly from the single pollutant models, with the exception of URS in the older cohort; in this case the association with PM_{10} was reduced in the joint pollutant model. In case of miscoding of symptoms, both URS and LRS were combined for each of the age groups. For the younger children, PM_{10} but not ozone was associated with symptoms, while for the older children, both pollutants were associated with symptoms.

Table 3 summarizes the results for different lags using the GAM, in which a smooth of time is used in place of dichotomous variables for month and year. The locally weighted smooth spanned about 3 months of data and therefore proxied the seasons of the year. This model generated stronger associations between the clinic visits and PM_{10}, relative to the model using ordinary least squares. For LRS in both cohorts, a 3-day lag demonstrated the strongest association, but the differences between alternative lags were not large. However, for URS and LRS in the older cohort and for LRS in the younger cohort, a 5-day moving average (days 0–4) generated much larger and stronger associations with PM_{10}. For ozone, only unlagged exposure was associated with clinic visits, with the exception of an association between a 1-day lag in ozone with URS in the older cohort. The effect was similar in magnitude and significance to the unlagged result.

Table 4 summarizes the results of different sensitivity analyses using the GAM. In the basic model, which included temperature, day of week and month, and a smooth of time, PM_{10} was statistically associated with lower respiratory visits in the young and older children. The results appeared relatively insensitive to the length of the span chosen. However, the inclusion of a monthly dichotomous variable reduced the magnitude of the effect. For example, for

lower respiratory visits for the younger cohort, the regression coefficient dropped from 0.19 to 0.05. Visual inspection of residual and autocorrelation function plots indicated an absence of any remaining serial correlation. Models that stratified on lower PM_{10} (PM_{10} <235 μg/m³) and warmer days (daily average temperature >8°C) generally produced results similar to the full models. One-hour maximum ozone concentrations were associated with upper and lower respiratory visits in the older cohort. In the multipollutant model, PM_{10} remained significantly associated with lower respiratory visits in both cohorts, while ozone was associated with lower and upper respiratory visits in the older cohort. The magnitude of the effect was slightly higher than that predicted from the ordinary least squares models. For example, for PM_{10} among the younger cohort, the coefficient for lower respiratory visits was 0.049 in the ordinary least squares model versus 0.052 in the GAM, while for upper respiratory visits, the coefficients were 0.066 versus 0.083, respectively. Additional smoothers of temperature did not alter the results for any of the end points. PM_{10} was not associated with nonrespiratory symptoms.

Table 5 summarizes some of the model results indicating the percent changes in clinic visits for lower respiratory visits for

Table 3. Alternative lags for PM_{10} using general additive model with Gaussian distribution for clinic visits for upper (URS) and lower respiratory (LRS) in young (<2 year old) and older (3–15 year old) children (estimated β-coefficient with standard error in parentheses)

PM_{10} lag	Young, LRS	Young, URS	Older, LRS	Older, URS
0	0.12 (0.02)#	0.01 (0.01)	0.20 (0.04)#	0.06 (0.02)**
1	0.15 (0.02)#	0.00 (0.01)	0.20 (0.04)#	0.05 (0.02)**
2	0.15 (0.02)#	0.01 (0.01)	0.20 (0.04)#	0.06 (0.02)**
3	0.19 (0.03)#	-0.01 (0.01)	0.28 (0.04)#	0.05 (0.02)*
4	0.15 (0.03)#	-0.01 (0.01)	0.20 (0.04)#	0.01 (0.02)
0 to 4 moving average	0.25 (0.03)#	-0.00 (0.01)	0.36 (0.05)#	0.14 (0.03)#

The model also includes daily average temperature (1-day lag), binary variables for day of week, and a Loess smooth of time.
*$p<0.05$; **$p<0.01$; #$p<0.001$.

Table 4. General additive model regression results for clinic visits for upper (URS) and lower respiratory symptoms (LRS) in young (<2 year old) and older (3–15 year old) children (estimated β-coefficient with standard error in parentheses)

	Young, LRS	Young, URS	Older, LRS	Older, URS
PM_{10}	0.052 (0.024)*	-0.021 (0.014)	0.083 (0.033)**	0.008 (0.026)
PM_{10}, less top 5% (< 235 μg/m³)	0.059 (0.026)*	-0.011 (0.016)	0.046 (0.035)	-0.004 (0.028)
PM_{10}, less coldest 10% (>8°C)	0.052 (0.023)*	-0.019 (0.015)	0.086 (0.033)**	0.006 (0.027)
PM_{10}, nonsummer months	0.039 (0.026)	-0.025 (0.17)	0.082 (0.030)**	0.012 (0.029)
PM_{10}, no month variable	0.186 (0.025)#	0.0003 (0.011)	0.279 (0.036)#	0.183 (0.028)#
PM_{10}, no month variable, 5-day moving average	0.140 (0.021)#	-0.003 (0.013)	0.263 (0.030)#	0.144 (0.026)#
Ozone	0.033 (0.034)	0.022 (0.020)	0.120 (0.047)**	0.123 (0.035)#
PM_{10} and ozone together				
PM_{10}	0.045 (0.024)*	-0.023 (0.014)	0.082 (0.032)**	0.008 (0.026)
Ozone	0.025 (0.038)	0.020 (0.020)	0.154 (0.046)#	0.131 (0.037)#

The model also includes daily average temperature (lagged one day), binary variables for day of week and month, and a Loess smooth of time.
PM_{10} (μg/m³) is lagged 3 days and ozone (ppb) is unlagged.
*$p<0.05$; **$p<0.01$; #$p<0.001$.

young and older children based on the GAM model. For children under age 2, a $50\text{-}\mu g/m^3$ change in PM_{10} (about half of the mean concentration) was generally associated with a 3% increase, increasing up to 9% in the model without month variables. For children age 3–15 years of age, the lower respiratory effects were in the range of 2–4% for a $50\text{-}\mu g/m^3$ change in PM_{10} (increasing to 13% in the model without month variables) and 5%/50 ppb change in ozone. Finally, for clinic visits attributed to upper respiratory visits, a 50-$\mu g/m^3$ change in the 5-day moving average of PM_{10} is associated with a 7% increase.

Discussion

The analysis indicates that PM_{10} is associated with clinic visits for lower respiratory visits in children 3–15 years of age and those under age 2. A prior study in Santiago reported a strong and consistent association between acute exposure to PM_{10} and mortality (2). The association existed for all-cause mortality as well as mortality associated with either cardiovascular- or respiratory-specific mortality. Prior to the current study, only a few efforts have been reported in the time–series epidemiologic literature linking air pollution to either mortality or morbidity among young children, particularly in non-Western industrialized countries. Several ecological studies have reported an association between particulate matter and neonatal or infant mortality (3–5,14)

Morbidity effects of particulate matter on children with asthma or asthmalike symptoms also have been reported from several panel studies in the United States and Western Europe using daily time–series data (15–17). Among panels that were not entirely composed of asthmatics, several studies have reported an association between PM_{10} and lower respiratory symptoms (18–20). Air pollution effects on children have also been demonstrated from daily data on emergency room visits (21,22).

As in all studies, our use of the Santiago data had both advantages and disadvantages. One of the principal advantages was that the health care professionals in the clinics included in our study were specifically trained in filling out the special diagnostic forms. Studies that use data on hospital admissions or emergency room visits often face difficulties in terms of accuracy and consistency of coding and compliance. An additional advantage was that for the subpopulation being served (lower and moderate income residents), these clinics are the primary provider of health care services. Therefore, the possibility of behaviors complicated by competing servers, health plans,

Table 5. Percent change in clinic visits for lower respiratory symptoms predicted from alternative models

	Young	Older
PM_{10}	2.5 (0.2–4.8)	3.7 (0.8–6.7)
PM_{10}, less top 5% (235 $\mu g/m^3$)	2.8 (0.4–5.3)	2.1 (-1.0–5.2)
PM_{10}, less coldest 10% (8°C)	2.5 (0.3–4.7)	3.9 (1.0–6.8)
PM_{10}, nonsummer months	1.9 (-0.6–4.3)	3.7 (1.0–6.3)
PM_{10}, no month variable	8.9 (6.6–11.3)	12.6 (9.4–15.7)
Ozone	1.6 (-1.6–4.8)	5.4 (1.3–9.6)

Values shown are percent change and 95% confidence interval associated with 50 $\mu g/m^3$ change in PM_{10} and 50 ppb change in ozone, the approximate interquartile range. Regresssion results are based on the general additive model, which includes daily average temperature, binary variables for day of week and month, and a Loess smooth of time. PM_{10} is lagged 3 days and ozone is unlagged.

insurance, and accessibility is minimized.

There are three main disadvantages of these data. First, the action of visiting a clinic is ultimately a subjective choice that can be influenced by several factors such as competing demands, parents' attention to illness, and the thresholds of discomfort of the children. However, it is reasonable to assume that these factors are randomized over the range of pollution concentrations and are not likely to vary on a day-to-day basis with air pollution. Therefore, omitting these factors from the analysis is unlikely to result in a significant estimation bias. Second, the public clinics primarily serve the lower 70% of the population income distribution, while citizens from the upper quintile are typically served by private clinics. Therefore, these estimates are not necessarily representative of all children in Santiago. If children from lower and moderate income families were more susceptible to the effects of air pollution, our estimates would have an upward bias in representing the entire population of children.

A third concern was that clinics are only open on weekdays and during normal working hours. Furthermore, the number of attending physicians varies on a daily basis at the clinics to keep up with demand, thus patients may have to wait for care. Therefore, some patients may be discouraged from seeking medical attention. Because the analysis indicates an association between PM_{10} and clinic visits, it is possible that on the higher air pollution days, visits are "artificially" reduced. This would result in a downward bias in the dose–response curve. Visual observation of the data suggests a leveling of the dose–response function at the higher levels of PM_{10}. It is unclear whether this is due to discouraged demand or to other factors, such as higher PM_{10} days being associated with less harmful blowing dust. As part of the analysis, other time–series models were investigated in an attempt to adequately take account of the potential influence of the supply of physician hours. A particular concern was the possibility that recorded respiratory visits

could be influenced causally by the availability of physicians, which in itself might be an endogenous variable if the number of physician hours varies with either pollution or meteorological variables. We used an instrumental variables approach and vector autoregressive techniques to examine the question of endogeneity. The results indicated that capacity constraints in clinics was not a problem in the estimation.

An additional concern was the lack of data on sulfur or nitrogen dioxide. While there has been little evidence of an acute morbidity effect of sulfur dioxide on the general population from the existing literature, European studies have reported an effect from nitrogen dioxide (23).

For lower respiratory visits in both infants and older children, a 3-day lag in PM_{10} appears to be most significant among the single-day lags. However, the cumulative exposure over a 5-day period generates the strongest effects. Several recent studies have reported that lags of 2 days or more are more strongly related to the health end point than are concurrent exposure [for example (16,17,21)]. The lag may be due to either delays in seeking medical care or to the pathogenesis of particulate matter in its potential impact on lung clearance. Upper respiratory visits in infants are more randomized throughout the year and are more difficult to model, as indicated by the low R^2 in those models. Part of the difficulty in modeling may be due to the greater role of an individual caregiver's attitude about the infant's need for medical attention. The results for multipollutant models suggest the possibility of effects from both particulate matter and ozone. Daily concentrations of particulate matter and ozone were not correlated over time. Further, as summarized in Tables 2 and 4, for most of the cohorts, the magnitude of the effect of one pollutant was not impacted by the inclusion of a second pollutant in the model. Particulate matter was associated with LRS in both the younger and older cohort, and ozone was associated with both ULS and LRS in the older cohort.

Because of concerns about potential confounding, we controlled for the effects of seasonality and temperature in several ways. The basic model included a variable representing daily temperature and dichotomous variables representing the month and year. We then analyzed the data using Loess smoothers for time, with and without variables representing the month of the study. We also analyzed the data after deleting the 5% of days with highest PM_{10} concentrations and the coldest 5% of days to ensure that the results were not driven by any extreme observations. The models were also rerun after deleting the summer months. With one exception, the results did not noticeably change with any of these analyses. Dropping the dichotomous variable for month significantly increased the estimated coefficient of PM_{10} suggesting that some overcorrection for season in the model may be occurring. Once season is successfully modeled through the smooth function of time, a causal independent effect of month is difficult to reconcile. These variables may borrow their effect from correlated variables such as pollution or meteorology. The possibility exists, therefore, that the magnitude of the effect of air pollution on morbidity visits is biased downward significantly when day of week, month, and smoothers are included. The problem of confounding in a multivariate model is an important one, and the inclusion of a broad array of sensitivity analyses—as applied here—is necessary to gain confidence both in the significance and magnitude of effects. Taken together, a significant effect of PM_{10} on lower respiratory disease does not appear be due to residual confounding by temperature or season.

Our analysis indicates that for children under 2 years of age a 50-μg/m^3 change in PM_{10} (the approximate interquartile range) is associated with a 4–12% increase LRS. For children 3–15 years of age the increase in LRS ranges from 3 to 9% for a 50-μg/m^3 change in PM_{10} and 5%/50 ppb change in ozone. These magnitudes are within the range of effects reported in studies undertaken in Western industrialized nations. For example, these studies suggest that a similar change in PM_{10} is associated with a 4% increase in hospital admissions, a 5% increase in emergency room visits, and a 15% increase in lower respiratory symptoms (24).

REFERENCES AND NOTES

1. Escudero J, Cofré A. Evaluación de los Instrumentos de Política para el control de la contaminación por emisiones vehiculares utilizados en al Región Metropolitana. CEP 222–272. Santiago, Chile:Medio Ambiente en Desarrollo, 1993.

2. Ostro BD, Sánchez JM, Aranda C, Eskeland GS. Air pollution and mortality: results from a study of Santiago, Chile. J Expo Anal Environ Epidemiol 6:97–114 (1996).

3. Bobak M, Leon M. Air pollution and infant mortality in the Czech Republic, 1986–1988. Lancet 340:1010–1014 (1992).

4. Penna MLF, Duchiade MP. Air pollution and infant mortality from pneumonia in the Rio de Janeiro metropolitan area. Bull Pan Am Health Org 25:47–54 (1991).

5. Woodruff TJ, Grillo J, Schoendorf KC. The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environ Health Perspect 105:608–612 (1997).

6. Ostro B. The Health Effects of Air Pollution: A Methodology with Applications to Jakarta. Washington, DC:The World Bank, 1992.

7. Aranda C, Astudillo P, Mancilla P, Caussade S, Girardi B, Gamboa R. Monitoreo. Epidemiológico de las enfermedades respiratorias infantiles. Kinesiología 36: 62–73 (1993).

8. Aranda C, Astudillo P, Mancilla P, Caussade S, Girardi, G, Gamboa R. Epidemiologic Monitoring of the Effects of Atmospheric Pollution on Respiratory Illness in Children. Santiago, Chile:UNICEF, 1992.

9. Instituto Nacional de Estadisticas. Proyecciones y estimaciones de población por sexo y edad, comunas 1980–1995. Fascículo F/CHI. Santiago, Chile:Región Metropolitana, 1989.

10. SAS. SAS System for Windows 3.1. Release 6.12. Cary, NC:SAS Institute Inc., 1997.

11. Cleveland WS, Devlin SJ. Robust locally-weighted regression and smoothing scatterplots. J Am Stat Assoc 74:829–836 (1988).

12. Statsci. S-Plus. Seattle, WA:Statsci, 1997.

13. Hastie T, Tibshirani R. Generalized Additive Models. London:Chapman and Hall, 1990.

14. Knoebel H, Chen C, Liang K. Sudden infant death syndrome in relation to weather and optimetrically measured air pollution in Taiwan. Pediatrics 96:1106–1110 (1995).

15. Ostro BD, Lipsett MJ, Mann JK, Braxton-Owens H, White M. Air pollution and asthma exacerbations among African-American children in Los Angeles. Inhal Toxicol 7:711–722 (1995).

16. Roemer W, Hoek G, Brunekreff B. Effect of ambient winter air pollution on respiratory health of children with chronic respiratory symptoms. Am Rev Res Dis 147:118–124 (1993).

17. Pope CA III, Dockery D. Acute health effects of PM_{10} pollution on symptomatic and asymptomatic children. Am Rev Respir Dis 145:1123–1128 (1992).

18. Schwartz J, Dockery D, Neas LM, Wypij D, Ware JH, Spengler JD, Koutrakis P, Speizer FE, Ferris BG. Acute effects of summer air pollution on respiratory symptom reported in children. Am J Respir Crit Care Med 150:1234–1242 (1994).

19. Braun-Fahrland C, Ackermann-Liebrich U, Schwartz J, Gnehm HP, Rutishauser M, Wanner HU. Air pollution and respiratory symptoms in preschool children. Am Rev Respir Dis 145:42–47 (1992).

20. Ostro BD, Lipsett MJ, Mann JK, Krupnick A, Harrington W. Air pollution and respiratory morbidity among adults in southern California. Am J Epidemiol 137:691–700 (1993).

21. Delfino RJ, Murphy-Moulton AM, Burnett RT, Brook JR, Becklake MR. Effects of air pollution on emergency room visits for respiratory illnesses in Montreal, Quebec. Am J Respir Crit Care Med 155:568–576 (1997).

22. Bates DV, Baker-Anderson M, Sizto R. Asthma attack periodicity: a study of hospital emergency visits in Vancouver. Environ Res 51:51–70 (1990).

23. Touloumi G, Katsouyanni K, Zmirou D, Schwartz J, Spix C, Ponce de Leon A; Tobias A, Quennel P, Rabczenko D, Bacharova L, et al. Short-term effects of ambient oxidant exposure on mortality: a combined analysis within the APHEA project. Am J Epidemiol 146:177–185 (1997).

24. Dockery DW, Pope CA III. Acute respiratory effects of particulate air pollution. Annu Rev Public Health 15:107–132 (1994).